Copy 6
RM E50G10

NACA RM E50G10

NACA

RESEARCH MEMORANDUM

EFFECT OF FUEL VOLATILITY ON ALTITUDE STARTING LIMITS OF A TURBOJET ENGINE

By H. D. Wilsted and J. C. Armstrong

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON
September 11, 1950

1368

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

EFFECT OF FUEL VOLATILITY ON ALTITUDE STARTING LIMITS OF A TURBOJET ENGINE

By H. D. Wilsted and J. C. Armstrong

SUMMARY

The lighter fractions of the AN-F-58 specification jet-engine fuel vaporize at the low pressures associated with high-altitude airplane operation where it is possible that as much as 15 percent of the fuel may be lost by evaporation. Use of fuels having a lower volatility than the AN-F-58 fuel would reduce evaporation losses but might change the altitude starting limits of an engine. The effect of fuel volatility on altitude starting limits of an axial-flow-compressor-type turbojet engine was therefore investigated using 1.1- and 5.4-pound-per-square-inch Reid vapor pressure fuels. The 5.4-pound Reid vapor pressure fuel used was an AN-F-58 specification fuel. The AN-F-58 fuel, at flight Mach numbers from 0.40 to 0.85, allowed consistent windmilling starts at 2000 to 8000 feet higher altitudes than obtained with the 1.1-pound Reid vapor pressure fuel. At a flight Mach number of 0.25, ignition could not be established at any altitude with the 1.1-pound-per-square-inch Reid vapor pressure fuel. The trend of increasing altitude starting limit with increasing fuel volatility appears to be general in that similar trends have been observed in earlier investigations with different fuels and engines.

INTRODUCTION

The need of the armed forces for a fuel available in greater quantities than that obtainable under the AN-F-32 and AN-F-48 fuel specifications has led to the proposal of AN-F-58 specification fuel. Potential availability per barrel of crude petroleum for this fuel is approximately 50 percent, compared with 6 percent for AN-F-32 and 12 percent for AN-F-48 specification fuels. One disadvantage of the AN-F-58 fuel, however, is that the lighter fractions vaporize at low pressure, which results in as much as 15-percent loss in fuel at altitude with unpressurized fuel cells. An additional loss may be incurred at high rates of climb if the escaping fuel vapor entrains liquid fuel.

1368

The NACA has accordingly undertaken a research program to determine how a reduction in the volatility of AN-F-58 fuel would affect the performance and operational characteristics of turbojet and ram-jet engines at altitude. The first fuel selected for investigation was an AN-F-58 fuel from which about 30 percent of the light ends had been removed to reduce the Reid vapor pressure to 1 pound per square inch. It has been estimated that so removing the lighter ends reduces the potential availability from crude petroleum to about 35 percent per barrel with optimum refining methods. The 1-pound Reid vapor pressure fuel can be described as having a relatively high potential availability and a negligible altitude vaporization loss.

In the investigation of the AN-F-58 fuel at the NACA Lewis laboratory (references 1 to 8), it was found that in comparison with AN-F-32 fuel the major effects on the characteristics of an engine were an increase in the maximum altitude at which the engine could be started under windmilling conditions and an increased rate of carbon deposition in the combustors. The present investigation determined the altitude starting limits of an axial-flow-compressor type turbojet engine having tubular type combustors. The results of this investigation indicate the effect of fuel volatility on the starting limits of an axial-flow-compressor type turbojet engine at simulated altitudes up to 40,000 feet and flight Mach numbers between 0.25 and 0.85. These starting limits were obtained for the original AN-F-58 base stock and for the base stock having the lighter ends removed to give a Reid vapor pressure of 1.1 pounds per square inch. Because carbon deposition rates can be determined more economically in single-combustor test rigs, this problem was not investigated in the full-scale engine.

APPARATUS

Fuels

The specifications of AN-F-58 fuel and the analyses of the AN-F-58 base stock and the nominal 1-pound-per-square-inch Reid vapor-pressure fuel used in this investigation are presented in table I. The analyses show the Reid vapor pressures of the two fuels to be 5.4 and 1.1 pounds per square inch, respectively. Other physical changes are also indicated, such as an increase in viscosity from 2.67 to 4.28 centistokes. This change is sufficient under very low fuel-flow conditions to alter the fuel-spray pattern from some fuel nozzles.

Power Plant

1368

The turbojet engine used in this investigation included an axial-flow compressor, eight through-flow, tubular-type combustors, and a single-stage turbine. The nominal thrust rating of the engine at sea-level conditions is 5000 pounds.

A schematic diagram of the ignition system used on this engine is presented in figure 1. The system was composed of a motor-generator unit supplying power at 115 volts to two ignition transformers which stepped up the voltage supplied to the two spark plugs to 15,000 volts. The spark plugs were mounted in the top and bottom combustors. The breakdown voltage across the spark-plug gaps with the spark plug removed from the engine was found to be 15,000 volts.

A fine adjustment of fuel flow for test purposes was obtained by substituting a pressure-regulating valve for the automatic fuel controls supplied with the engine. A schematic diagram of the modified fuel system is shown in figure 2.

Altitude Chamber

The engine was installed in the altitude chamber on a thrust frame connected through linkage to a null-type thrust indicating cell located outside the test chamber (fig. 3). The ram-air pressure was adjusted by remote-controlled butterfly valves in the air supply line near the entrance to the altitude chamber. Air was supplied to the engine at temperatures corresponding approximately to NACA standard altitude conditions. Accurate adjustment of air temperature was made by use of electric heaters in a bypass line immediately preceding the entrance to the altitude chamber. The air entered the altitude chamber, passed through straightening vanes, and entered the engine.

The test section of the altitude chamber was separated from the exhaust portion of the chamber by a bulkhead. The tail pipe passed through the bulkhead through a seal composed of three floating asbestos rings so installed as to allow axial movement required by engine expansion and thrust mechanism and to allow approximately 1 inch of lateral motion to prevent binding.

The engine exhaust gases were discharged into a diffuser located directly downstream of the jet nozzle. From the diffuser, the exhaust gases passed through coolers and control valves into the laboratory exhaust systems. The exhaust portion of the altitude chamber was maintained at the pressure corresponding to the NACA standard atmospheric pressure for the altitude being simulated. 1368

Instrumentation

Pressure and temperature instrumentation was installed in front of and behind each engine component at the stations indicated in figure 4. The instrumentation used in the windmilling-characteristic investigation is described in the appendix. A brief description of the instrumentation used in the altitude-starting investigation follows. Cowl-inlet pressure and temperature were measured by means of four total-head tubes and four iron-constantan thermocouples equally spaced circumferentially around the center line of the annulus at the cowl inlet, station 1. A bayonet-type, chromel-alumel thermocouple probe was installed in each combustor outlet, station 6, and connected to dial-type indicators. Engine tail-pipe temperatures were measured by four chromel-alumel thermocouples equally spaced about the periphery of the diffuser at station 7. These thermocouples protruded into the gas stream about 3 inches.

The temperature of the fuel entering the engine was measured by an iron-constantan thermocouple in the fuel line. Fuel-flow rates were measured by two calibrated rotameters.

PROCEDURE

The method of altitude starting used in this investigation was to set the exhaust-section pressure to correspond to the desired altitude and the engine-inlet pressure and temperature to correspond to the particular altitude and flight Mach number. The engine wind-milling speed was allowed to stabilize; ignition was then turned on and the throttle slowly opened. If ignition was not immediately obtained, the throttle was manipulated to vary the fuel flow over a wide range. When ignition was not obtained in 45 seconds, the fuel was automatically shut off by a timing device. The engine and exhaust system were purged by windmilling the engine for 5 minutes before each attempt to start.

When ignition was obtained, the approximate fuel flow at the time of ignition, the time elapsed from opening of throttle, and the number of combustors ignited by spark plugs were recorded. When the flame had propagated to all combustors, the elapsed time was again recorded; if however, propagation was incomplete, the number of each combustor operating was recorded.

Windmilling characteristics (for example, rotor pressure, temperature, and velocities) were determined for a range of simulated altitudes and flight speeds to aid in the analysis of starting-limit trends.

The cowl-inlet and altitude exhaust pressures used to simulate the various altitudes and flight Mach numbers were controlled to within 0.1 inch of mercury. The compressor-inlet temperature was generally held to within 10° F of the NACA standard temperature for each simulated flight condition; except that at altitudes above 20,000 feet at the low flight Mach numbers the lowest temperatures obtainable, 0 to -20° F, were higher than the standard altitude temperatures. Fuel temperatures were not controlled but the temperature of the fuel trapped in the engine fuel system and in the fuel lines inside the altitude chamber would tend to follow the air temperature within the chamber. Based on the fuel trapped inside the altitude chamber and the measured fuel flows at the time of ignition, it is estimated that ignition obtained within 10 seconds of opening the throttle at the 0.85 flight Mach number and within 30 seconds of opening the throttle at the 0.25 flight Mach number conditions probably did not involve a change in fuel temperature. When longer periods were involved, the fuel temperature rapidly approached the 70° F fuel storage temperature. The engine speed was read to the nearest 10 rpm. The sequence of ignition in the combustor could be observed on gages connected to the thermocouples in each combustor outlet.

A tabulation of the symbols used herein and the methods of computation are presented in the appendix.

RESULTS AND DISCUSSION

Such factors as combustor configuration, operational conditions, and fuel properties, which affect ignition in gas-turbine engines, have been individually investigated (references 9 to 12). From these investigations the following criterions for good combustor-starting characteristics have evolved: (1) high pressure and temperature and low velocity in the combustors; (2) a fuel-vapor to air mixture near stoichiometric in the spark-plug gap, which requires either a relatively volatile or well-atomized fuel, and a well-formed fuel-spray pattern over the starting speed range and under the lowest fuel temperature likely to be encountered; and (3) sufficient spark energy for ignition at the existing pressure 1368 and velocity conditions. Although the investigation discussed herein is concerned primarily with the effects of fuel volatility, the other factors involved may be of importance if under the conditions investigated any of these factors become marginal. Because the engine configuration was unchanged and the same flight conditions were reproduced for both fuels used in this investigation, the only factors that should result in differences in altitude starting limits are those affected by fuel properties such as fuel vaporization, atomization, and spray pattern.

Windmilling Characteristics

Although differences in altitude starting limits for the two fuels used in this investigation are expected to be influenced only by differences in fuel properties, the general trends of the starting characteristics with altitude and flight Mach number are dependent on the environment in the combustors under the existing windmilling conditions. The variations of engine speed, air flow, and combustor environment as defined by the combustor-inlet pressures, temperatures, and velocities are presented in table II. These data corrected from altitude test conditions to NACA standard altitude conditions are presented in figures 5 to 7. The major corrections required were largely due to the inability to maintain the low temperatures at the engine inlet for the simulated high-altitude, low-flight Mach-number conditions.

An increase in flight Mach number (fig. 5) was accompanied by a rise in windmilling engine speed as a direct result of the increased pressure ratio across the engine. The air flow (fig. 6) increased rapidly with flight Mach number but decreased with increasing altitude in approximately the proportions that would be predicted from the altitude correction factors. Comparison of the sea-level corrected air flow (from table II) at a constant engine speed has shown, however, that the high-altitude, windmilling air flow is actually slightly less than would be predicted from sea level or low altitude air flow. This probably results from a Reynolds number effect on the internal flow. This effect is also reflected in the sea-level corrected pressure data.

Combustor pressures, temperatures, and velocities based on the maximum cross-sectional area of the combustor (station 5) were computed from pressure and temperature measurements at the compressor outlet, the engine air flow, and fluid passage areas. As shown in figure 7, the combustor static pressures, static temperatures, and velocities increased with increasing flight Mach number and decreased with increasing altitude. Figure 7(d) indicates that combustor-inlet velocity is a function only of the engine windmilling speed.

Altitude Starting Characteristics

The results of the altitude-starting investigation are presented in table III. The run numbers identify the sequence of the starting attempts.

The starting data for the AN-F-58 specification fuel is presented in figure 8. The sharp decrease in the altitude at which starting was possible as the flight Mach number was increased is attributed to the rapid rise in air velocity through the combustors with increasing flight Mach number as was shown in figure 7. At a flight Mach number of 0.25, both the ignition limit and the flame propagation limit were apparently reached between altitudes of 35,000 and 40,000 feet. When flame propagation to all burners could not be achieved, sustained engine operation was impossible.

The starting data for the 1.1-pound-per-square-inch Reid vapor-pressure fuel is presented in figure 9. As the flight Mach number was raised above 0.40, the altitude at which consistent starts could be accomplished decreased in the manner experienced with the higher volatility fuel. Ignition was not possible at a flight Mach number of 0.25, even though this series of starting attempts contained successful starts at higher flight Mach numbers, which indicated that the failure to start at 0.25 Mach number was not due to fouling of the spark plugs. Also, bench runs of the fuel nozzles showed that good spray-cone patterns were formed at the fuel rates recorded at the 0.25 Mach number windmilling conditions; therefore, the failure to start was not attributed to deterioration of the fuel-spray pattern. In view of the higher fuel viscosity (table I), it is possible that even though a fully developed conical spray pattern was obtained the fuel atomization was not as effective as at the high fuel-flow rates and that larger fuel particles would reduce the rate of fuel vaporization and thereby create a fuel-vapor to air ratio too weak for ignition. In addition, the larger fuel particles could have had a greater quenching effect than would result from finer particles at higher fuel-flow rates. Further investigation is required before a complete explanation can be made of this failure to start at the 0.25 flight Mach number. It is of interest, however, that similar breaks in the low flight Mach number altitude starting limits have been observed in other engines (references 1 and 2). Unreported data indicate that the failure of the engine to start at the 0.25 flight Mach number, low-altitude conditions could be overcome by somewhat better atomization of the fuel and a slightly greater penetration of the spark plug into the combustion chamber or by an increase in spark energy.

A comparison of the altitude starting limits of the two fuels is shown in figure 10. The more volatile AN-F-58 fuel with a Reid vapor pressure of 5.4 pounds per square inch allows consistent starting at altitudes about 2000 to 8000 feet higher than the 1-pound Reid vapor pressure fuel at flight Mach numbers between 0.85 and 0.40. The higher altitude starting limits with increased fuel volatility is similar to that experienced at the NACA Lewis laboratory in previous starting investigations in comparing AN-F-58 fuel performance with other fuels in a number of turbojet engines (references 1 to 4).

CONCLUDING REMARKS

The results of this investigation substantiate the trends of earlier investigations in that an increase in fuel volatility generally increased the altitude at which consistent engine starts could be obtained. The 5.4-pound-per-square-inch Reid vapor pressure fuel (AN-F-58) allowed consistent windmilling starts at altitudes 2000 to 8000 feet higher than were obtained with the 1.1-pound-per-square-inch Reid vapor pressure fuel at flight Mach numbers between 0.40 and 0.85. At a simulated flight Mach number of 0.25, ignition could not be established at any altitude with the 1.1-pound-per-square-inch Reid vapor pressure fuel. Fuel nozzles designed to provide better atomization for higher viscosity fuels and increased spark energy will probably make it possible to ignite the lower volatility fuels over a satisfactory range of flight conditions.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

APPENDIX - CALCULATIONS

Symbols

A	area, sq ft
c_p	specific heat at constant pressure, Btu/(lb-$^{\circ}$F)
g	acceleration due to gravity, 32.2 ft/sec^2
M	Mach number
N	engine speed, rpm
P	total pressure, lb/sq ft absolute
p	static pressure, lb/sq ft absolute
R	gas constant, 53.3 ft-lb/(lb)($^{\circ}$R)
T	total temperature, $^{\circ}$R
t	static temperature, $^{\circ}$R
V	velocity, ft/sec
W_a	air flow, lb/sec
γ	ratio of specific heat at constant pressure to specific heat at constant volume
δ	ratio of altitude absolute static pressure to absolute static pressure of NACA standard atmosphere at sea level
θ	ratio of altitude absolute static temperature to absolute static temperature of NACA standard atmosphere at sea level

Subscripts: (fig. 4)

0	free stream
4	compressor outlet
5	combustor inlet

Methods of Calculation

Air flow. - Engine air flow was computed from the instrumentation at station 4. The data were computed from the one-dimensional, compressible-flow equation: 1368

$$W_a = A_4 \frac{P_4}{\sqrt{RT_4}} \sqrt{2g \frac{\gamma}{\gamma-1}\left[\left(\frac{p_4}{P_4}\right)^{\frac{2}{\gamma}} - \left(\frac{p_4}{P_4}\right)^{\frac{\gamma+1}{\gamma}}\right]} \tag{1}$$

where

A_4 was computed from dimensions taken from engineering drawings.

P_4 was indicated by a total-pressure tube in each of four compressor-diffuser outlets. Each total-pressure tube was installed at the average pressure location as determined by an earlier complete pressure survey of the diffuser outlets.

p_4 was measured by 4 wall static orifices at the compressor outlet.

T_4 was measured by an iron-constantan aspirating-type thermocouple in each of four compressor-diffuser outlets. The impact-recovery coefficient for this type thermocouple is approximately 0.98 and the indicated temperature is essentially a total or stagnation temperature. The probe was installed at the average temperature location as determined by a temperature survey.

γ was taken as 1.40.

Combustor-inlet temperature. - The approximate combustor-inlet static temperature was computed from the area ratio of station 4 to station 5 assuming isentropic diffusion. The area at station 5 (combustor inlet) was taken as the maximum combustor cross-sectional area.

From continuity of flow,

$$W_a = \frac{p_4}{Rt_4} A_4 V_4 = \frac{p_5}{Rt_5} A_5 V_5 \tag{2}$$

1368

and from the conservation of energy equation,

$$V_5 = \sqrt{2gJc_p\ (T_4-t_5)} \tag{3}$$

and

$$V_4 = \sqrt{2gJc_p\ (T_4-t_4)} \tag{4}$$

Combining equations (2), (3), and (4) and substituting

$$p_4\left(\frac{t_5}{t_4}\right)^{\frac{\gamma}{\gamma-1}}$$

for p_5 gives

$$\frac{A_5}{A_4} = \left(\frac{t_4}{t_5}\right)^{\frac{1}{\gamma-1}} \sqrt{\frac{T_4-t_4}{T_4-t_5}} \tag{5}$$

where

A_5 was computed from dimensions taken from engineering drawings

t_4 was computed from the isentropic relation

$$t_4 = T_4\left(\frac{p_4}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$$

t_5 was then obtained by systematically substituting values in equation (5).

Combustor-inlet pressure. - Combustor-inlet static pressure was computed from the isentropic relation

$$p_5 = p_4\left(\frac{t_5}{t_4}\right)^{\frac{\gamma}{\gamma-1}} \tag{6}$$

<u>Combustor-inlet velocity</u>. - Combustor-inlet velocity based on maximum cross-sectional area was calculated from the continuity equation 368

$$V_5 = \frac{Rt_5 \, W_a}{p_5 \, A_5} \tag{7}$$

<u>Mach number</u>. - Flight Mach number was computed from the equation

$$M_0 = \frac{V_0}{g\gamma Rt_0} = \sqrt{\frac{2}{\gamma - 1}\left[\left(\frac{p_1}{p_0}\right)^{\frac{\gamma-1}{\gamma}}\right] - 1} \tag{8}$$

REFERENCES

1. Wilsted, H. D., and Armstrong, J. C.: Comparison of Performance of AN-F-58 and AN-F-32 Fuels in J33-A-23 Turbojet Engine. NACA RM E8K24, 1949.

2. Dowman, Harry W., and Younger, George G.: Comparison of Performance of AN-F-58 Fuel and Gasoline in J34-WE-22 Turbojet Engine. NACA RM E8L10a, 1949.

3. Meyer, Carl L.: Altitude-Wind-Tunnel Investigation of AN-F-58 Fuel in Experimental Version of J47 Turbojet Engine. NACA RM E8L13, 1949.

4. Acker, Loren, W., and Kleinknecht, Kenneth S.: Comparison of Flight Performance of AN-F-58 and AN-F-32 Fuels in J35 Turbojet Engine. NACA RM E8L02, 1949.

5. Cook, William P., and Koch, Richard G.: Altitude Performance of AN-F-58 Fuels in British Rolls-Royce Nene Single Combustor. NACA RM E9D08, 1949.

6. Stricker, Edward G., and Rayle, Warren D.: Altitude Performance of AN-F-58 Fuels in J35-C-3 Single Combustor. NACA RM E8L20a, 1949.

7. Dittrich, Ralph T., and Jackson, Joseph L.: Altitude Performance of AN-F-58 Fuels in J33-A-21 Single Combustor. NACA RM E8L24, 1949.

8. Swett, Clyde C., Jr.: Investigation of Spark Gaps Subjected to Altitude and Air-Velocity Conditions. NACA RM E8I17, 1948.

1368 9. Childs, J. Howard, McCaffetry, Richard J., and Surine, Oakley W.: Effect of Combustor-Inlet Conditions on Performance of An Annular Turbojet Combustor. NACA Rep. 881, 1947.

10. Holderness, F. H.: Some Observations on Diffusion Flames at Low Pressures. Rep. No. R-3, British R.A.E., Aug. 1946.

11. Marlow, B., and Dunning, J. E. P.: Ignition Tests on Goblin Turbine Engine Combustion Chamber under Simulated Altitude Windmilling Conditions. Tech. Note No. Aero. 1863, S. D. 51, British R.A.E., Jan. 1947.

1368

TABLE I - FUEL ANALYSES

	Specification AN-F-58a	Analysis: AN-F-58[a]	Analysis: 1.1-pound Reid vapor-pressure fuel[b]
ASTM distillation, °F:			
Initial boiling point	-------------	110	210
Percent evaporated			
5	-------------	135	224
10	-------------	157	243
20	-------------	198	276
30	-------------	230	302
40	-------------	272	328
50	-------------	314	355
60	-------------	351	384
70	-------------	388	413
80	-------------	427	441
90	400 (min.)	473	478
Final boiling point (max.)	600	560	560
Residue (max. percent)	1.5	1.0	1.0
Loss (max. percent)	1.5	1.0	1.0
Freezing point, °F (max.)	-76	Below -76	Below -76
Aromatics (max. percent by volume):			
ASTM D-875-46T	25	17	21
Silica Gel	-------------	19	23.5
Viscosity (max. centistokes at -40° F)	-------------	2.67	4.28
Bromine number (max.)	30.0	13.8	7
Reid vapor pressure (lb/sq in.)	5 to 7	5.4	1.1
Hydrogen-Carbon ratio	-------------	0.163	0.157
Heat of combustion (min. Btu/lb)	18,400	18,640	18,560
Specific gravity (max.)	0.802	0.769	0.803
Accelerated gum, (max. mg/100 ml)	20.0	2.9	-------------
Air jet residue (max. mg/100 ml)	10.0	3	-------------
Sulfur, (max. percent by weight)	0.50	0.03	-------------

[a]NACA fuel number 48-249
[b]NACA fuel number 49-246

[redacted]

TABLE II - WINDMILLING DATA

Run	Flight Mach number	Altitude (ft)	Cowl-inlet total pressure P_1 (lb/sq ft)	Free-stream static pressure p_0 (lb/sq ft)	Cowl-inlet total temperature T_1 (°R)	Engine speed (rpm) N	Engine speed (rpm) Altitude corrected N (a)	Engine speed (rpm) Sea-level corrected $N/\sqrt{\theta}$ (b)	Air flow (lb/sec) W_a	Air flow (lb/sec) Altitude corrected W_a (a)	Air flow (lb/sec) Sea-level corrected $W_a/\sqrt{\theta}$ (b)	Combustor-inlet static pressure (lb/sq ft) p_5	Combustor-inlet static pressure (lb/sq ft) Altitude corrected p_5 (a)	Combustor-inlet static pressure (lb/sq ft) Sea-level corrected p_5/δ (b)	Combustor-inlet static temperature (°R) t_5	Combustor-inlet static temperature (°R) Altitude corrected t_5 (a)	Combustor-inlet static temperature (°R) Sea-level corrected t_5/θ (b)	Combustor-inlet velocity (ft/sec) V_5	Combustor-inlet velocity (ft/sec) Altitude corrected V_5 (a)	Combustor-inlet velocity (ft/sec) Sea-level corrected $V_5/\sqrt{\theta}$ (b)
6	0.25	20,000	1015	972	451	879	880	950	3.2	3.2	6.4	980	980	2133	460	451	525	20	20	21
12	.25	30,000	652.4	625.7	433	764	739	850	2.8	2.9	8.7	623	630	2124	432	415	524	26	25	29
11	.25	40,000	410.2	391.7	456	685	640	740	1.1	1.1	5.4	386	391	2110	460	391	518	16	16	18
4	.40	20,000	1091	976	453	1450	1464	1580	6.5	6.4	12.9	1015	1015	2208	455	463	537	39	39	42
9	.40	40,000	437.0	391.0	442	1342	1284	1480	1.9	2.0	9.5	404	406	2186	441	402	532	28	27	31
3	.60	20,000	1239	971.5	473	2266	2282	2460	10.8	10.6	21.4	1108	1111	2417	463	490	568	62	62	67
5	.60	25,000	1001	784	456	2217	2228	2450	7.7	7.7	18.9	886	889	2397	464	468	566	54	54	60
8	.60	40,000	497.8	391.0	433	2077	2048	2360	4.0	4.1	19.2	436	441	2382	439	426	564	54	53	61
1	.85	20,000	1556	970.6	505	3323	3347	3610	19.7	19.6	39.6	1389	1392	3029	536	543	630	102	102	110
2	.85	25,000	1264	786.4	490	3265	3270	3590	15.5	15.4	37.8	1115	1108	2987	521	521	630	97	97	107
7	.85	40,000	630.5	394.7	439	2938	2973	3420	7.5	7.3	34.3	540	534	2881	463	472	625	85	87	100

NACA

[a]Corrected to standard ambient conditions at simulated altitude.

[b]Corrected to standard ambient sea-level conditions.

[redacted]

TABLE III - ALTITUDE STARTING DATA

Run	Flight Mach number	Altitude (ft)	Initial fuel temperature (°F)	Cowl-inlet temperature (°F)	Engine windmilling speed (rpm)	Ignition		Propagation	
						Combustors ignited (a)	Time for ignition (sec)	Combustors lighted	Time for propagation (sec)
1.1 pound per square inch Reid vapor-pressure fuel									
86	0.25	sea level	24	5	1000	none	--	---	--
87	.25	sea level	23	0	1000	none	--	---	--
85	.25	5,000	24	12	980	none	--	---	--
83	.25	10,000	24	23	990	none	--	---	--
82	.25	10,000	10	17	980	none	--	---	--
81	.25	15,000	0	7	950	none	--	---	--
93	.25	15,000	15	0	930	none	--	---	--
61	.25	20,000	5	0	900	none	--	---	--
79	.25	20,000	11	-7	860	none	--	---	--
92	.25	20,000	15	0	900	none	--	---	--
80	.25	25,000	-7	-17	920	none	--	---	--
60	.25	25,000	0	-23	834	none	--	---	--
91	.25	25,000	20	14	930	none	--	---	--
59	.25	30,000	0	-25	834	none	--	---	--
89	.25	30,000	20	-25	900	1	30	all	0
90	.25	30,000	20	15	910	none	--	---	--
88	.25	35,000	21	-8	860	none	--	---	--
12	.40	5,000	52	50	1610	1, 5	8	all	4
84	.40	15,000	25	15	1520	1, 5	20	all	5
76	.40	20,000	15	0	1450	1, 5	11	all	0
75	.40	20,000	5	-5	1480	1, 5	13	all	7
77	.40	25,000	12	-15	1465	none	--	---	--
78	.40	25,000	9	-19	1465	none	--	---	--
63	.60	5,000	80	75	2450	1, 5	5	all	0
64	.60	10,000	68	50	2410	1	7	all	5
5	.60	15,000	50	40	2320	1, 5	9	all	0
6	.60	15,000	55	39	2320	1, 5	27	all	5
74	.60	15,000	55	36	2300	1, 5	4	all	16
13	.60	15,000	55	35	2340	1	15	all	40
68	.60	15,000	65	35	2300	1, 5	7	all	0
11	.60	15,000	40	30	2340	none	--	---	--
18	.60	20,000	40	22	2300	1	30	all	10
30	.60	20,000	20	21	3260	1, 5	25	all	15
31	.60	20,000	40	21	3280	1	5	all	20
69	.60	20,000	49	21	2280	none	--	---	--
70	.60	20,000	43	21	2280	none	--	---	--
7	.60	20,000	30	20	2280	1	12	all	15
14	.60	20,000	50	20	2280	1	20	all	25
9	.60	20,000	35	19	2260	none	--	---	--
16	.60	20,000	55	18	2260	none	--	---	--
8	.60	20,000	25	16	2260	none	--	---	--
10	.60	20,000	35	15	2260	none	--	---	--
15	.60	20,000	50	15	2260	1	20	all	12
17	.60	20,000	35	15	2260	none	--	---	--
1	.60	25,000	10	0	2200	none	--	---	--
2	.60	25,000	10	-2	2200	none	--	---	--
19	.80	10,000	80	90	3230	1	12	all	12

[a]Spark plugs located in top and bottom combustors, 1 and 5, respectively.

1368

3

1368

TABLE III - ALTITUDE STARTING DATA - Concluded

Run	Flight Mach number	Altitude (ft)	Initial fuel temperature (°F)	Cowl-inlet temperature (°F)	Engine windmilling speed (rpm)	Ignition		Propagation	
						Combustors ignited (a)	Time for ignition (sec)	Combustors lighted	Time for propagation (sec)
1.1 pound per square inch Reid vapor-pressure fuel									
67	0.85	5,000	90	93	3010	1, 5	4	all	0
66	.85	5,000	83	89	2990	1, 5	4	all	0
62	.85	10,000	85	92	3490	none	--	---	--
21	.85	10,000	90	92	3520	1, 5	4	all	0
20	.85	10,000	85	90	3520	1, 5	14	all	5
65	.85	10,000	71	80	3450	none	--	---	--
23	.85	15,000	75	75	3470	1	5	all	5
22	.85	15,000	72	73	3450	1, 5	6	all	3
71	.85	15,000	69	72	3430	1, 5	3	all	0
72	.85	15,000	75	72	3430	none	--	---	--
73	.85	15,000	75	72	3450	none	--	---	--
24	.85	20,000	60	55	3360	5	20	all	30
29	.85	20,000	52	52	3360	1	20	all	10
3	.85	20,000	40	50	3320	none	--	---	--
4	.85	20,000	55	50	3320	none	--	---	--
25	.85	20,000	52	44	3340	1, 5	30	all	2
26	.85	25,000	50	35	3250	none	--	---	--
27	.85	25,000	48	27	3240	none	--	---	--
28	.85	25,000	54	26	3240	none	--	---	--
AN-F-58 fuel									
55	.25	35,000	0	-11	742	5	21	4, 5	--
57	.25	35,000	5	-12	834	5	30	all	45
51	.25	35,000	-10	-15	870	5	21	all	29
56	.25	35,000	10	-15	797	5	20	all	30
54	.25	40,000	10	2	760	none	--	---	--
52	.25	40,000	20	0	723	none	--	---	--
53	.25	40,000	0	0	686	5	45	5	--
58	.25	40,000	20	-1	630	none	--	---	--
44	.40	25,000	0	-4	1460	5	10	all	13
45	.40	30,000	5	-10	1390	1	20	all	10
48	.40	30,000	20	-10	1410	none	--	---	--
49	.40	30,000	20	-10	1390	1, 5	40	all	0
50	.40	30,000	20	-10	1390	1	18	all	4
46	.40	35,000	0	-10	1430	none	--	---	--
47	.40	35,000	10	-14	1410	none	--	---	--
37	.60	15,000	50	34	2340	1, 5	6	all	0
39	.60	20,000	50	23	2260	none	--	---	--
38	.60	20,000	40	19	2280	1	4	all	8
40	.60	20,000	50	19	2250	1	8	all	7
41	.60	20,000	35	16	2260	1	7	all	18
42	.60	25,000	30	0	2260	none	--	---	--
43	.60	25,000	25	0	2190	none	--	---	--
36	.85	10,000	90	95	3520	1, 5	25	all	0
34	.85	10,000	81	93	3520	none	--	---	--
35	.85	10,000	90	92	3540	1, 5	9	all	0
32	.85	15,000	75	78	3450	none	--	---	--
33	.85	15,000	80	75	3410	none	--	---	--

[a]Spark plugs located in top and bottom combustors, 1 and 5, respectively.

[redacted]

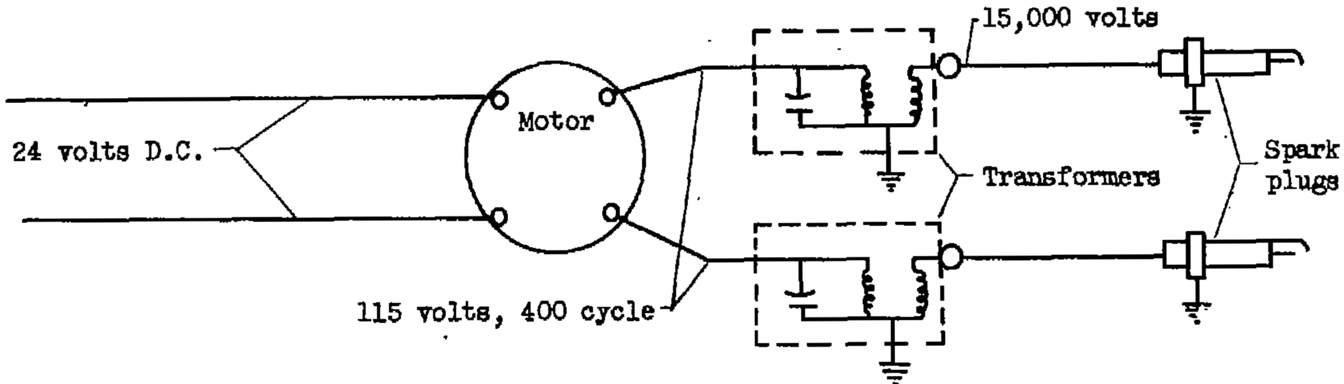


Figure 1. - Schematic diagram of ignition system.

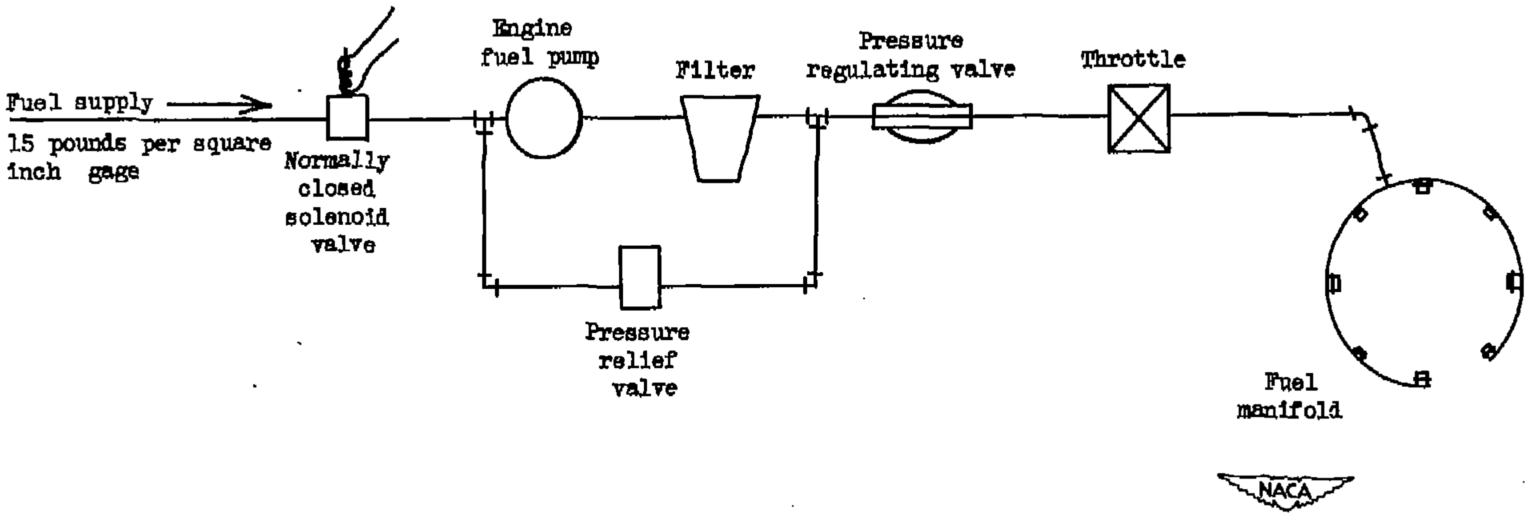


Figure 2. - Schematic diagram of revised fuel system.

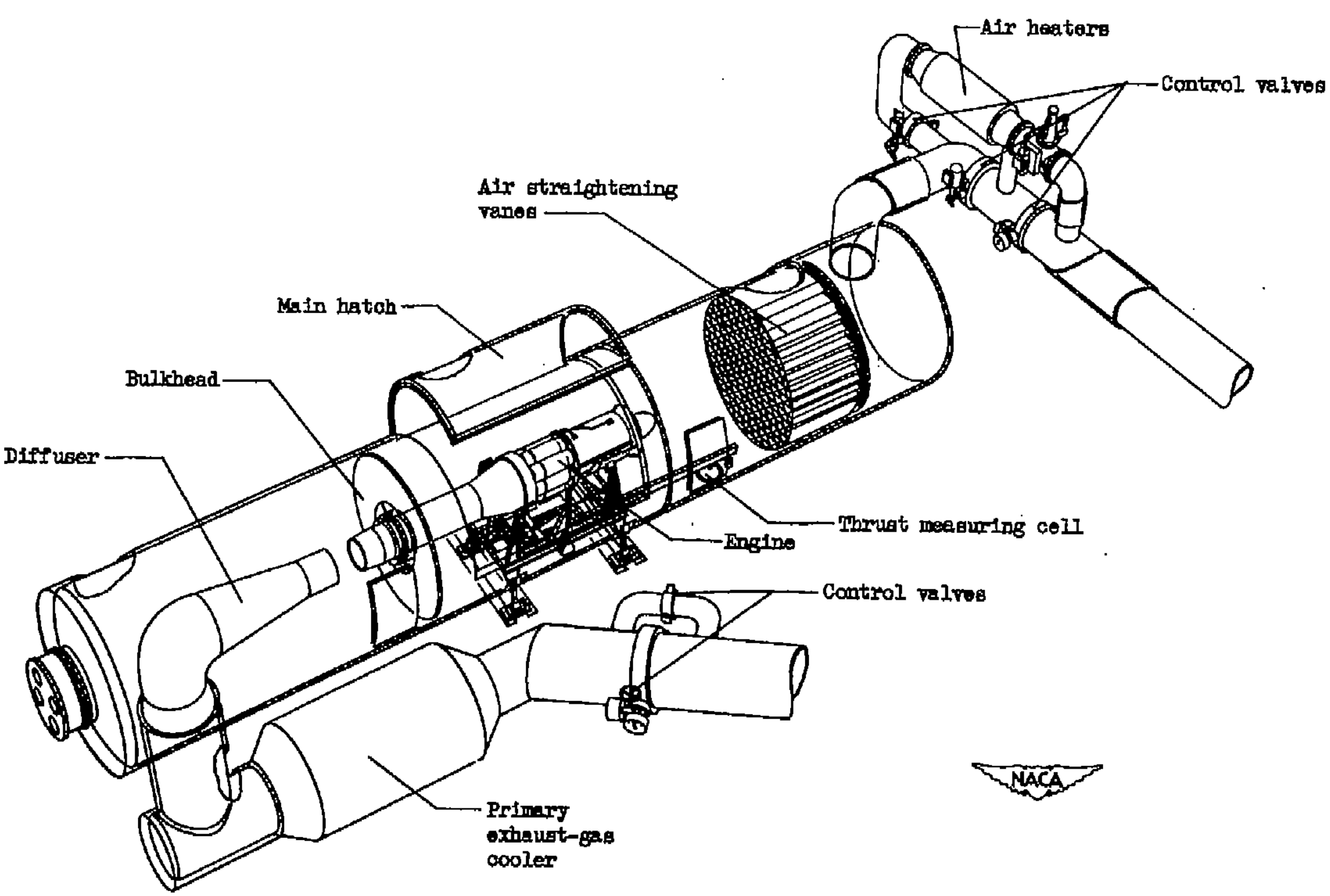


Figure 3. - Altitude chamber with an engine installed.

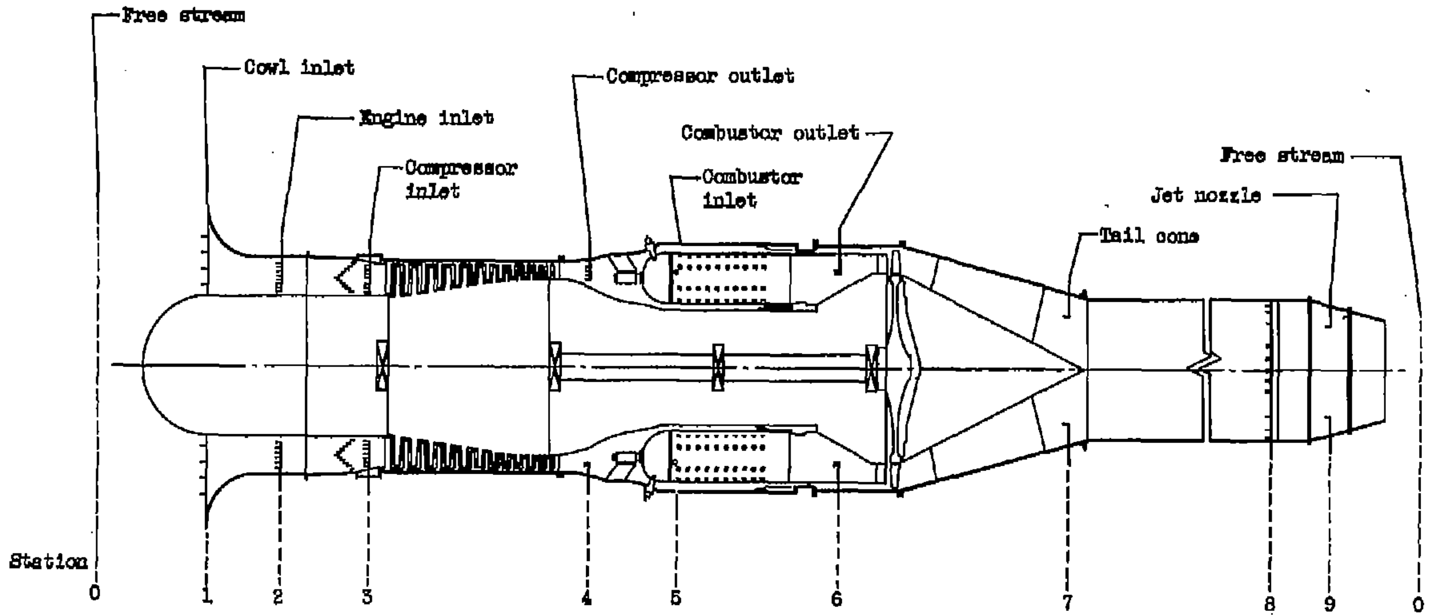


Figure 4. - Engine instrumentation stations.

[redacted]

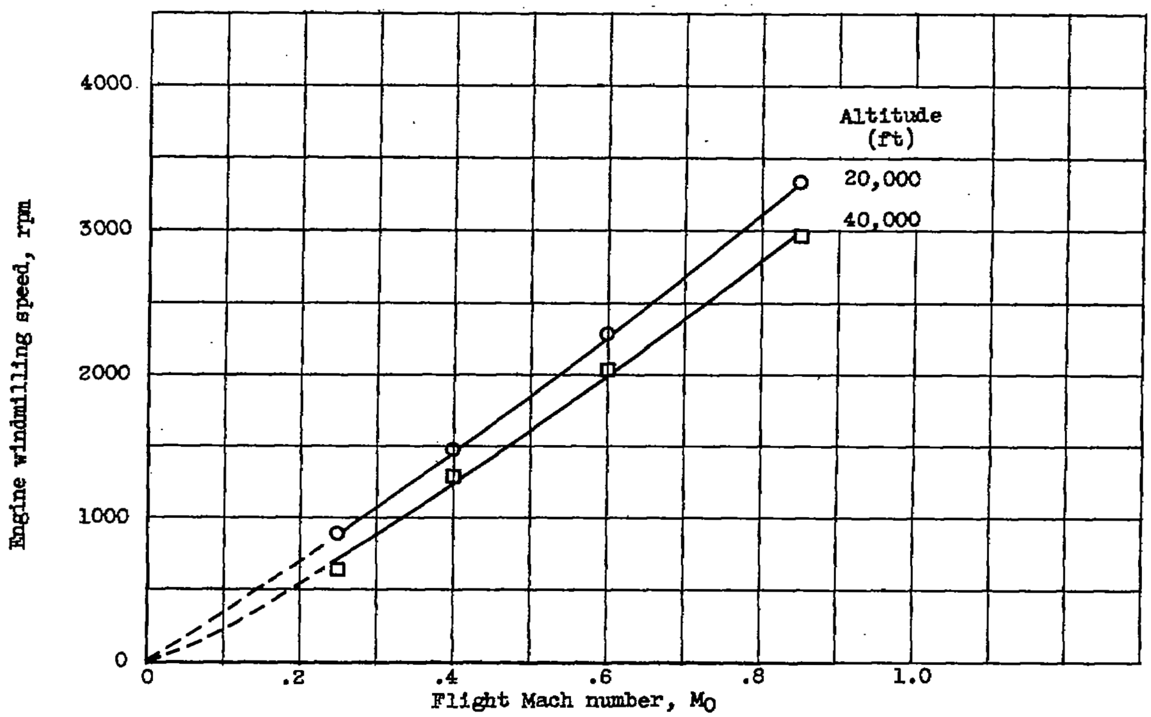


Figure 5. - Variation of engine windmilling speed with flight Mach number and altitude.

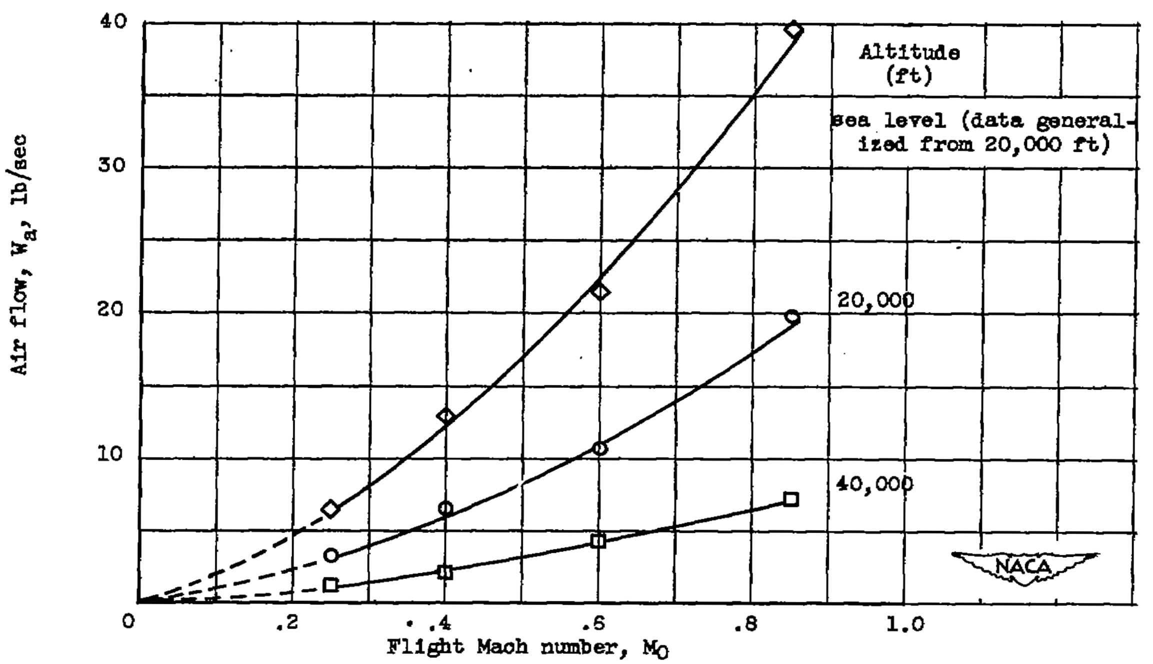
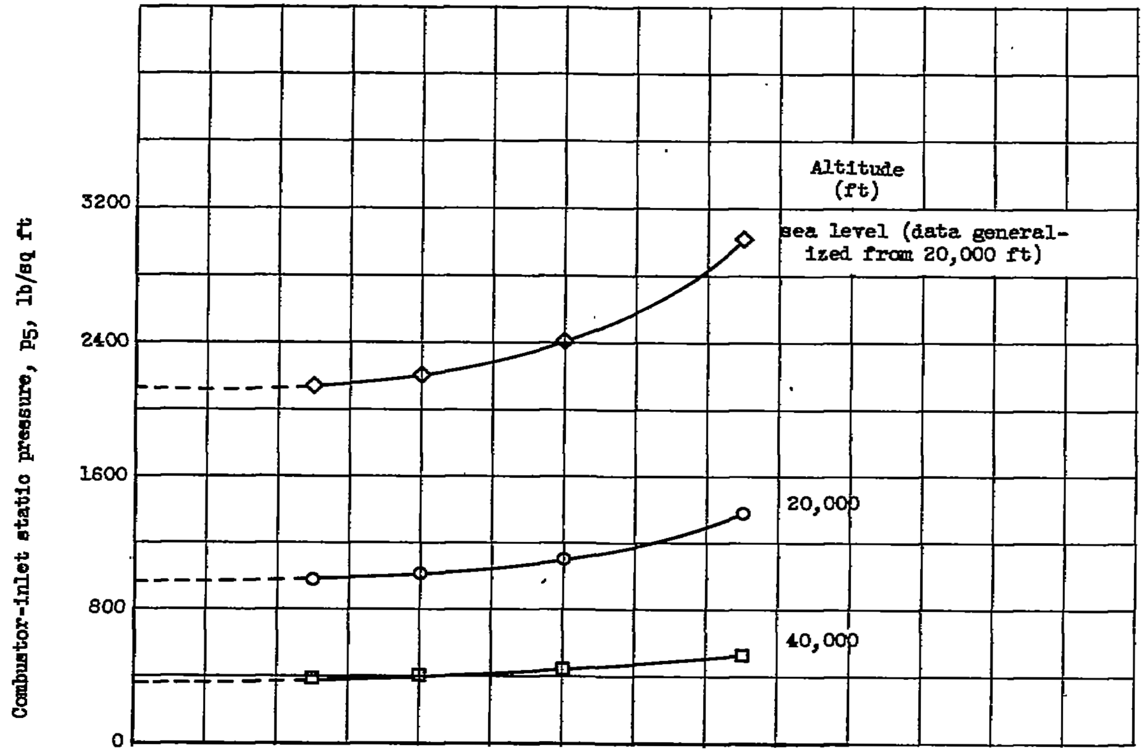


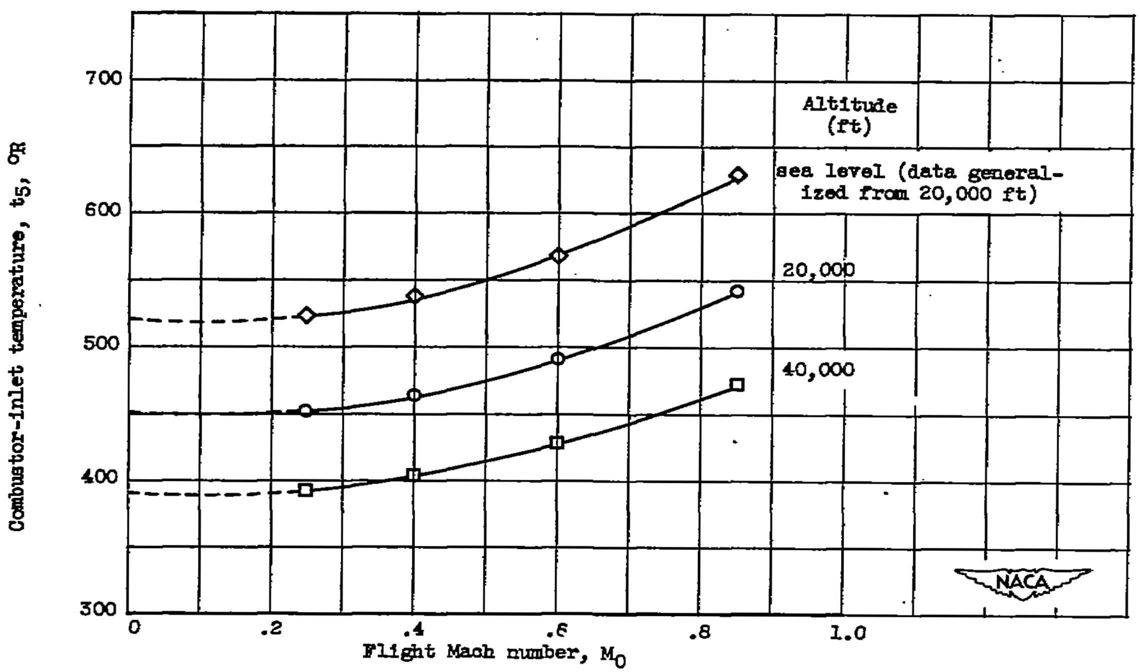
Figure 6. - Variation of air flow with flight Mach number and altitude.

1368

1368

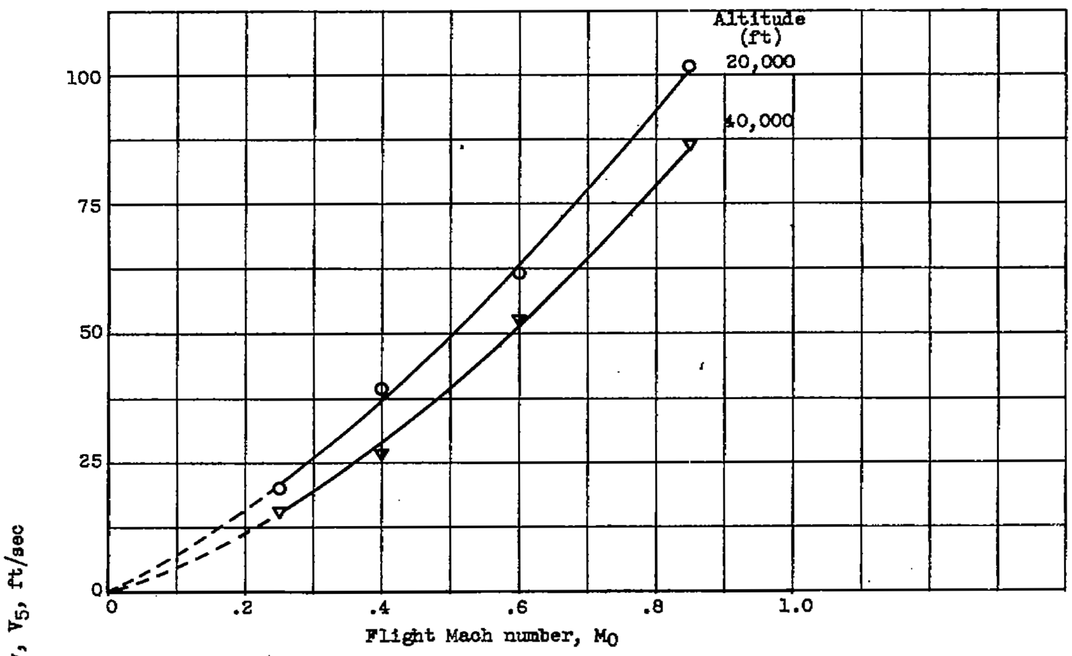


(a) Combustor-inlet static pressure.

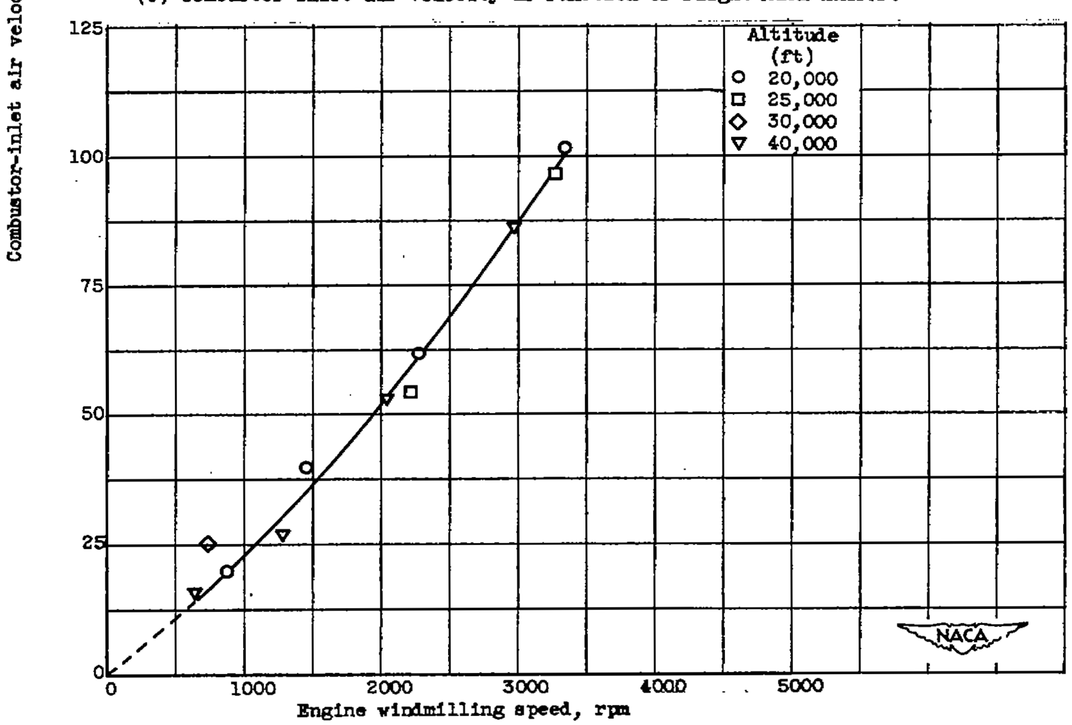


(b) Combustor-inlet temperature.

Figure 7. - Variation of combustor-inlet conditions with flight Mach number and altitude.



(c) Combustor-inlet air velocity as function of flight Mach number.



(d) Combustor-inlet air velocity as function of engine windmilling speed.

Figure 7. - Concluded. Variation of combustor-inlet conditions with flight Mach number and altitude.

1368

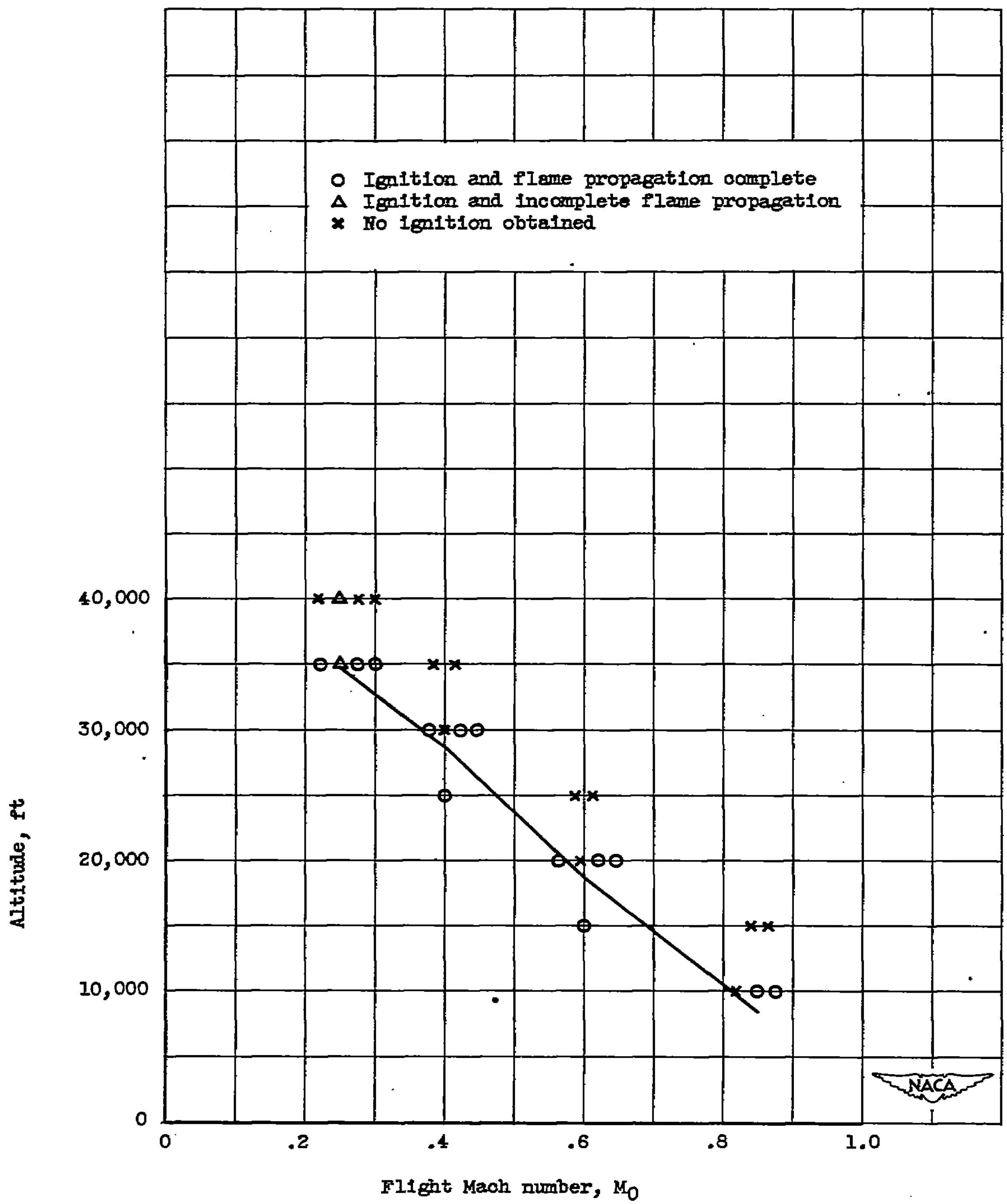


Figure 8. - Altitude starting limits of turbojet engine with AN-F-58 fuel (Reid vapor pressure, 5.4 lb/sq in.).

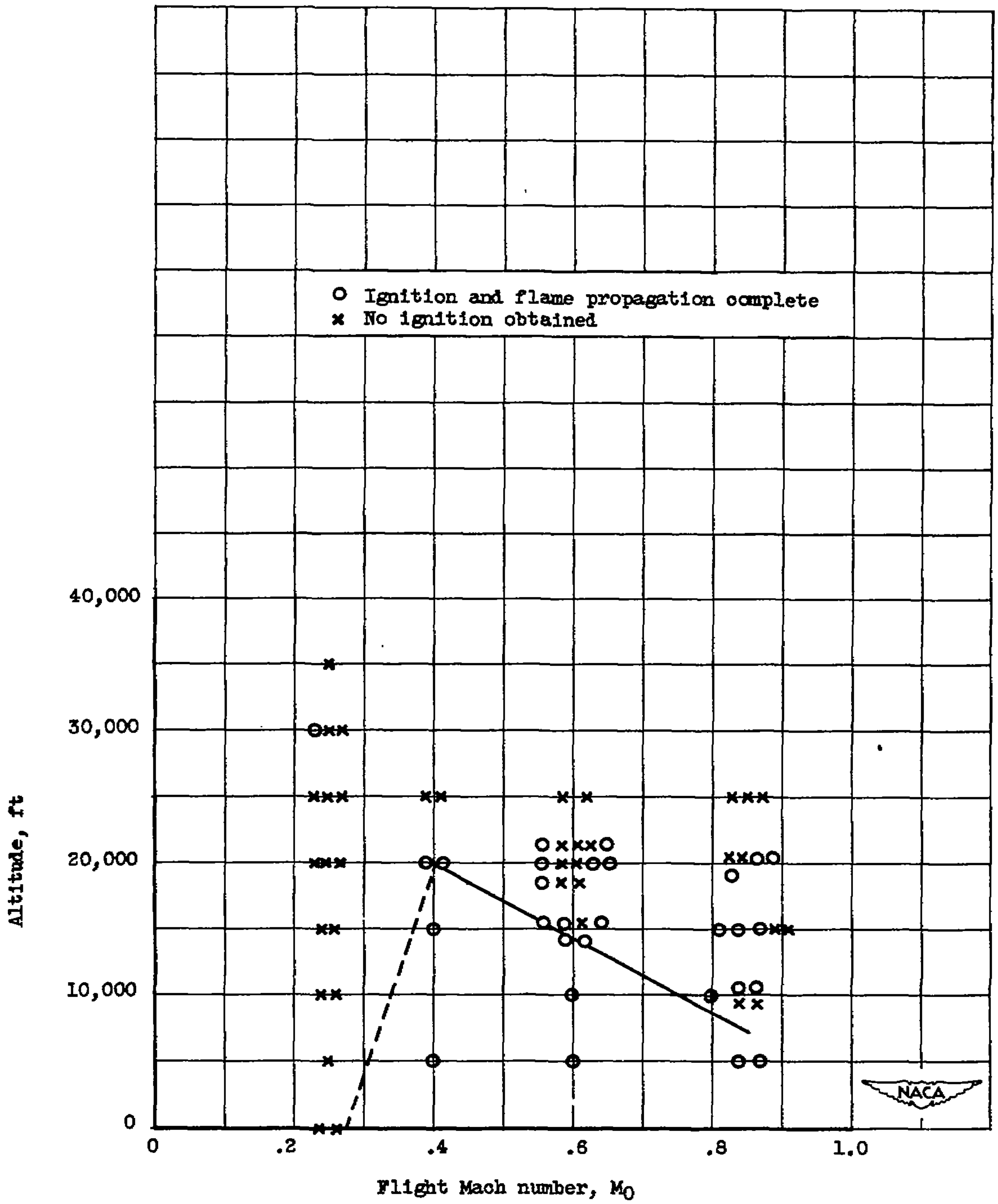


Figure 9. - Altitude starting limits of turbojet engine with 1.1-pound-per-square-inch Reid vapor pressure fuel.

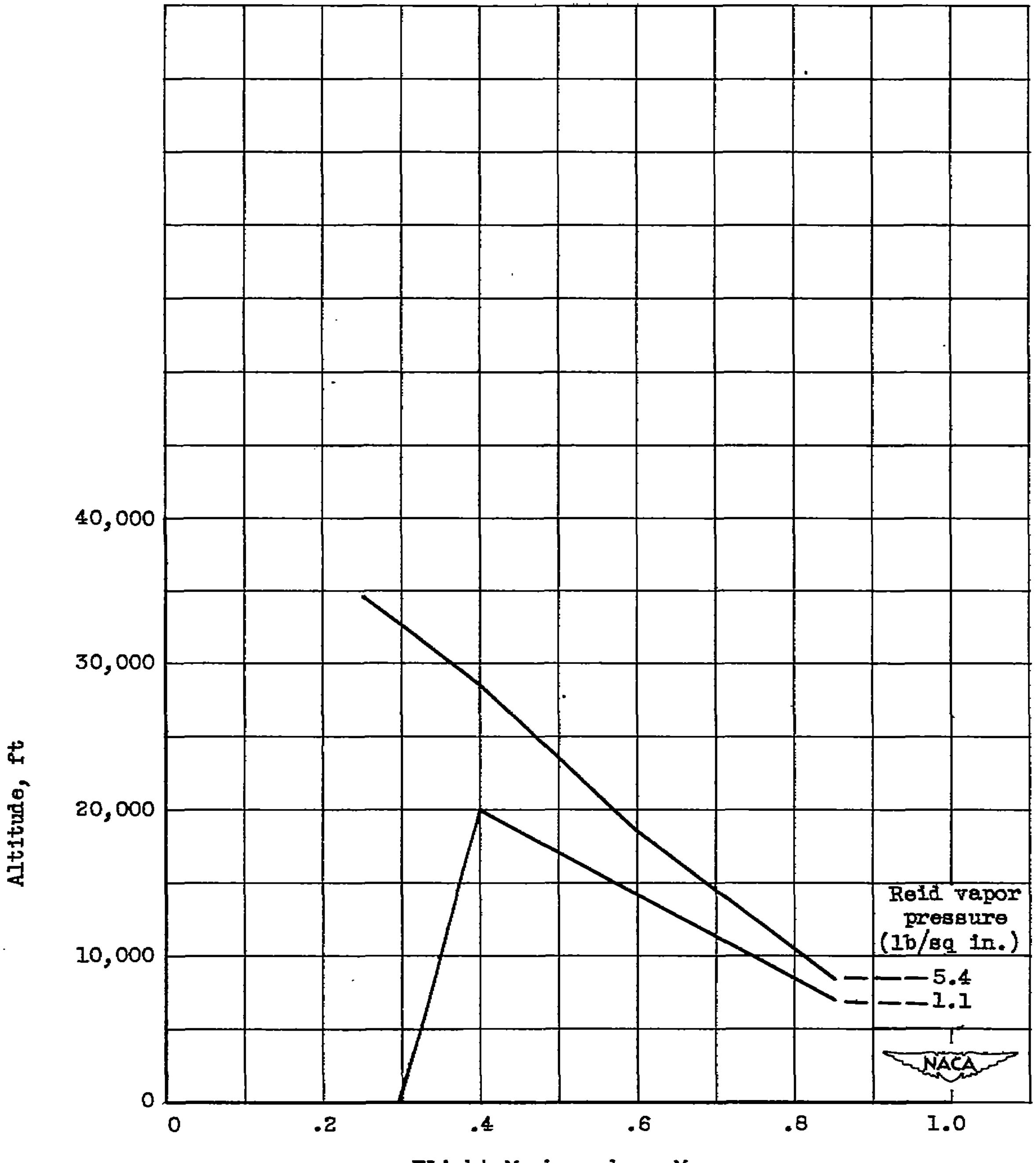


Figure 10. - Comparison of altitude starting limits of an AN-F-58 and a 1.1-pound-per-square-inch Reid vapor pressure fuel in a turbojet engine.

NACA-Langley - 9-11-50 - 300